First Generation Systems

- Basic Architecture: AMPS, NMT, etc. similar
- Mobile telephone switching office (MisTO) connects base stations to PSTN,
- Subscriber location and equipment databases were local to each geographical service area (CGSA) (e.g., MSA or RSA)
- Could only move about locally!
Intersystem Operation

Intersystem operation problem

- How to support handoffs and roaming between CGSA’s within a operator’s network or between different operator’s networks if a roaming agreement in place and they support the same air interface.

Intersystem Operation

- First Generation Systems: AMPS, NMT, etc.
  - Limited interoperability
    - AMPS service provider could not handoff calls between their own CGSA’s or support roaming between them
    - No roaming across systems of the same type but of different service providers
  - Why?
    - Legal hurdles, billing problems, propriety systems in the backhaul as 1G standards are air interface standard only, basically didn’t think it would be needed
- Initial Intersystem Operation Solutions (ad-hoc in nature)
  - Manual – through a clearing house – required phone ahead scheduling
  - Follow Me Roaming – GTE system - automated clearing house approach
Clearing House Based Roaming

Intersystem Operation
Follow Me Roaming

Figure 8.8 Follow-me roaming system. After [19]
Mobility Management

• Mobility Management Problems
  1. Location Management
     • Track location of users for incoming calls within a CGSA
       and allowing user to roam between CGSA service areas
       of a service provider while having the ability to
       place/receive calls, also support roaming among different
       service providers supporting the same air interface
       standard
     • Location registration/authentication/paging
  2. Handoff Management
     – Maintain in progress connection as user moves
     • (Handoff/rerouting) within systems, between systems

Mobility Management Standards

• IS-41 (several revs: IS-95, IS-54, AMPS)
• GSM-MAP (Mobile Application Part)
• ITU-T (E.750 series)

Location Management
Handoff Management

• GSM standard developed first, then IS-41,
• ITU –T: specifies performance standards
• All three are based on a system architecture
Basic PCS Architecture

VLR – local database of subscriber information
HLR – central database of subscriber info

IS-41 Architecture Reference

AC: authentication center  HLR: home location register
BS: base station  ISDN: integrated services digital network
CSS: cellular subscriber station (terminal)  MSC: mobile switching center (MTSO)
EIR: equipment identity register  PSTN: public switched telephone network
VLR: visitor location register

AC: authentication center  HLR: home location register
BS: base station  ISDN: integrated services digital network
CSS: cellular subscriber station (terminal)  MSC: mobile switching center (MTSO)
EIR: equipment identity register  PSTN: public switched telephone network
VLR: visitor location register
**GSM System Architecture**

- **VLR** = Visitor Location Register
- **HLR** = Home Location Register
- **EIR** = Equipment Identity Register
- **AUC** = Authentication Center
- **BTS** = Base Transceiver Station
- **ADC** = Admission Data Center
- **OMC** = Operation Maintenance Center

**Location Management**

- **Location Area (LA)**
  - Divide coverage into non-overlapping groups of cells
  - Assign each LA a unique id
  - Location Area ID is periodically broadcast by each cell
  - As a mobile moves/turns phone on – it listens to location area id – depending on the approach – it may perform a location update/authentication procedure to provide it’s location to VLR and possibly HLR

- **Two level database hierarchy HLR/VLR**
  - HLR points to VLR where mobile located
  - VLR entry points to LA where mobile last located

- **In large networks may have HLR split among regions with aggregate info cross region**
Location Area and Cell Identification Parameter

MNC – Mobile Network Code
Identifies the GSM operator within the country. In AMPS system the network code is the system ID (SID)

LAC – Location Area Code
Defines a location area, which consists of a group of cells. Each MNC will have several LACs.

CI – Cell Identity
Uniquely identifies a cell in a location area.

Location Management

- Location Management involves two main tasks to support mobile receiving incoming calls and roaming
  - Location Registration/update
    - Mobile informs network of location using reverse control channels
    - May include an authentication step here as well
  - Paging
    - Network informs mobile of incoming call
    - Broadcast over group of cells (paging area) on forward control channels
- Tradeoff: registration/updating and paging
Location Registration

- Location Registration involves signaling to VLR and possible HLR
- Two Types of Location Registration
  1. Intra – VLR (LAs attached to same VLR)
     - Only change LA id in VLR (local signaling)
     - Target ITU-T location update time $\leq 2$ sec
  2. Inter –VLR (LAs attached to different VLR)
     - must signal HLR to update VLR pointer
     - Target ITU-T Location update time $\leq 4$ sec

Inter-VLR Location Update

- Walkthrough Inter-VLR case
  1. Mobile powers up scans reverse control channels, locks on to strongest signal. Listens to forward broadcast control channel until Location Area ID heard
  2. Since Location Area ID differs from last one mobile registered in mobile signals on reverse control channel to serving MSC, MSC signals HLR update VLR pointer
  3. AUC verifies user- may issue challenge/response authentication procedure
  4. HLR – gives VLR mobile service profile
  5. HLR – deregisters mobile from last VLR location
   Target ITU-T bound on location registration $\leq 4$ sec
Inter-VLR Location update in GSM

1. The MS sends the Location Update request to the VLR (new) via the BSS and MSC.
2. The VLR sends a Location Update message to the HLR serving the MS which includes the address of the VLR (new) and the IMSI of the MS. This updating of the HLR is not required if the new LA is served by the same VLR as the old LA.
3. The service and security related data for the MS is downloaded to the new VLR.
4. The MS is sent an acknowledgement of successful location update.
5. The HRL requests the old VLR to delete data relating to the relocated MS.
Location Management

- Location Update Techniques in practice
  - Timer based periodic registration (AMPS)
  - LA crossing based (cell broadcast LA id)
    - NA-TDMA, IS-95, GSM, 3G systems
  - Hybrid LA crossing + timer based (GSM)
  - Distance Based (IS-95)

- Paging Techniques
  - Paging Area (PA) usually same at LA but doesn’t have to be
  - Blanket polling commonly deployed (page all cells simultaneously)
  - If no response after a fixed number of attempts – give up and roll over to voice mailbox
  - Target ITU-bound on paging delay time = 4 sec

Mobile Terminated Call Example

- Assume a mobile has registered it's location with VLR and HLR
- 1: calling a mobile subscriber
- 2: forwarding call to GMSC
- 3: signal call setup to HLR
- 4, 5: request status from VLR
- 6: forward responsible MSC to GMSC
- 7: forward call to serving MSC
- 8, 9: get current status and LAI of MS
- 10, 11: Paging of MS
- 12, 13: MS answers
- 14, 15: security checks
- 16, 17: set up connection
Tradeoff between Location Update and Paging

1 cell = 1 location area
Frequent location updates and a minimal paging in a cell

whole service area (SA) = 1 location area
No location updates in SA and a large number of pages

Obviously must balance location update traffic load and paging load to minimize overhead to the network and battery drain on mobile

Rate of Paging Messenger per LA (x 10^5 paging/hour/LA)
Total LU rate (x 10^5 LU/hour)

Tradeoff between LU and Paging
Location Management

Problems with current approach

- High overhead
- Power consumption in mobile terminals
- Location update traffic unequally distributed among cells in a location area (edge cells get more traffic)
- Performance dependent on LA/PA design
- Highly increase in signaling traffic for location update and great deal of current/ongoing research

The LA techniques can be classified at either
- static - location areas fixed based on geography
- dynamic – location areas change over time

A Classification of Location Update Techniques

<table>
<thead>
<tr>
<th>Location Update Schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static Approach</strong></td>
</tr>
<tr>
<td>A fixed location area size</td>
</tr>
<tr>
<td>Reporting center</td>
</tr>
<tr>
<td>Zone/ Location Area/ Geographical-based</td>
</tr>
<tr>
<td><strong>Dynamic Approach</strong></td>
</tr>
<tr>
<td>A dynamic location area size</td>
</tr>
<tr>
<td>Time-based</td>
</tr>
<tr>
<td>Movement-based</td>
</tr>
<tr>
<td>Distance-based</td>
</tr>
<tr>
<td>Multi-layered or overlapped location area</td>
</tr>
<tr>
<td>Load Adaptive</td>
</tr>
<tr>
<td>Profile-based</td>
</tr>
<tr>
<td>Contention-free</td>
</tr>
</tbody>
</table>
Static Location Update Techniques

- Reporting Centers
  - MS will update only in a reporting cell
- Zone/Location area/geographical-based
  - MS will update when it roams into a new location area

<table>
<thead>
<tr>
<th>Current Schemes</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATIC LOCATION AREA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reporting Centers</td>
<td>Simplicity, increase paging accuracy</td>
<td>High signaling traffic in the reporting cells</td>
</tr>
<tr>
<td>Zone/Geographical/Location-based</td>
<td>Simplicity</td>
<td>Useless location update, high load at the boundary of LA</td>
</tr>
</tbody>
</table>

Dynamic Location Update Techniques

- Time-based
  - Perform an update every $t$ period of time
- Movement-based
  - Update when the number of cell boundary crossings exceeds a threshold
- Distance-based
  - Perform an update when user’s distance from the latest update exceeds the threshold
A Classification of Location Update Techniques

- **Load Adaptive**
  - Consider user mobility and signaling load on the network
  - Perform more update in low loaded cells and few update in high loaded cells
- **Profile-based**
  - User movement is highly predictable.
  - System maintains a record of each user’s most likely itinerary
  - The mobile keeps track of the list of LA \( \{A_i\} \)
- **Multi-Layered or Overlapped location area (shadow cluster)**
  - Update every time mobile user cross the boundary of location area
  - Then MS is placed at the center of the new LA area

Paging Techniques

- Paging aims to quickly locate the mobile users to be able to deliver the call within a time constraint.
- **Interesting question**
  - What is the optimal size of the paging area?
  - What is the tolerance delay for the network?
    - (4 seconds suggested by ITU)
- **Paging Techniques:**
  - Simultaneous (Blanket Polling)
  - Sequential (Selective Paging, Intelligent Paging)
Paging Techniques

- Sequential Paging
  - Selective Paging
    - Page small group of cells around last registered location
    - (VLR keeps track of cell + LA)
    - No response then page the rest of LA
  - Intelligent Paging
    - The network determines the paging strategy
    - If the current traffic load is lower than a certain threshold, send a blanking polling.
    - Otherwise use some sort of selective paging

Handoff Management

- Call in progress Mobility management
- Radio Mobility (Handoff or Handover) (BSC or MSC)
  - Based on air interface standard
  - Hard Handoff (break before make)
  - Soft Handoff (make before break)
  - Mobile Assisted Handoff (MAHO)

- Handoff measurement: major decision-making stages
  - Identify the need
  - Identify the candidate
  - Evaluate the candidates
  - Select a target cell
RSS (received signal strength) based

- RSS is the direct indication of actual received energy at the mobile
- Controlled parameters: threshold level, hysteresis margin H and averaging interval

Handoff Management

- Two categories of handoff
  - Intrasystem handoff (3 cases)
    - Intracell handoff (different sector of same cell)
    - Standard Handoff (cells attached to same BSC)
    - Inter BSC handoff (same MSC)
  - Intersystem handoff
    - Cells attached to two different MSCs
    - Require specialized signaling
    - IS-41, GSM -MAP protocol
    - Three cases
      A. Handoff Forward
      B. Handoff Back
      C. Handoff to a Third
Types of Handoff

Intracell Standard Inter-BSC Intersystem handoff

MSC MSC MSC MSC

BTS BTS BTS BTS

BSC BSC BSC BSC

MSC MSC MSC MSC

MS MS MS MS

The situation after a handoff forward from System A (anchor system) to System B (serving system).

Intersystem Handoff – Handoff Forward

MSC-B MSC-A

PSTN

Telcom 2720
Handoff Forward

**Table 4.2** MSC Status Before, During, and After a Handoff Procedure

<table>
<thead>
<tr>
<th>Call begins</th>
<th>Anchor</th>
<th>Serving</th>
<th>Candidate</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal approaches service area of MSC-B</td>
<td>MSC-A</td>
<td>MSC-A</td>
<td>MSC-B</td>
<td></td>
</tr>
<tr>
<td>MSC-A decides to transfer call to MSC-B</td>
<td>MSC-A</td>
<td>MSC-A</td>
<td></td>
<td>MSC-B</td>
</tr>
<tr>
<td>Handoff complete</td>
<td>MSC-A</td>
<td>MSC-B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Goodman Figure 4.11** IS-41 Message sequence and system operations for handoff forward.

New MSC - Prior MSC

New Base station - Prior Base station

New Terminal - Prior Terminal

Detect weak signal

Handoff request

MEASUREMENT REQUEST INVOKE

Measurement request

Measure signal strength

Measurement report

MEASUREMENT REQUEST RESULT
Handoff Forward

<table>
<thead>
<tr>
<th>New MSC</th>
<th>New Base station</th>
<th>Terminal</th>
<th>Prior Base station</th>
<th>Prior MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Handoff phase</td>
<td>FACILITY DIRECTIVE INVOKE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Select new voice ch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FACILITY DIRECTIVE RESULT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transmit new SAT</td>
<td>Handoff command</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Send ST for 50 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turn off transmitter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tune to new voice ch.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Review new SAT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turn on transmitter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transmit new SAT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detect SAT</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confirm voice ch. connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MOBILE ON CHANNEL INVOKE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Handoff Back

After a Handoff Forward From MSC1 to MSC2
User may move back to a cell attached to anchor MSC 1—use HANDOFF BACK command to prevent call going from MSC1 to MSC2 back to MSC1 in wired network Called the shoelace effect
Handoff Back

Handoff Back signalling in IS-41

<table>
<thead>
<tr>
<th>New MSC</th>
<th>New Base Station</th>
<th>Terminal</th>
<th>Prior Base Station</th>
<th>Prior MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- handoff phase
- select new voice channel
- transmit new SAT
- handoff command
- hand ST for 50 ms
- turn off transmitter
- tune to new voice channel
- receive new SAT
- turn on transmitter
- transmit new BAT
- detect SAT
- confirm voice channel connection
- FACILITIES RELEASE PHONE
- FACILITIES RELEASE RESULT

Trombone Effect

As user moves route several handoff Forwards can occur resulting in non optimal routing in wired network part - called the Trombone Effect
Trombone Effect

Simple Case of two Handoff Forwards – results in the call path shown above after handoff forward to System C.
Current Solution is HANDOFF to a THIRD command

Handoff to a Third

• If there are circuits connecting MSC-A and MSC-C, the system can perform handoff to third with this result.
• Yields better routes in wired network
Handoff to a Third

Handoff to a third signalling in IS-41

MSC-C MSC-B MSC-A
New New New
Base Base Base
Station Station Station

Prior Prior Prior
Phase Station Station

Handoff to a third signalling in IS-41